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VSH-MX-008-3

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ENGINEERING REPORT NO. 8990

GEMS STUDY PROGRAM

SUMMARY FINAL REPORT

DATE: October 20, 1967

PREPARED FOR: SPO 27203

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ACKNOWLEDGEMENTS

The GEMS Study program could not have been successfully completed without the assistance received from various customer facility personnel. The author wishes to thank all the individuals who contributed their time and efforts to the Psychophysical GEMS experiment.

A special expression of gratitude is extended to [redacted] who 25X1A
did a fine job of coordinating customer-[redacted] who 25X1A
aided us in acquiring the system parameters information and conducting the psychophysical experiment.

SECTION I

GEMS STUDY PROGRAM

1.1 INTRODUCTION

The GEMS Study program has been successfully completed. The program efforts succeeded in accomplishing the major objectives. Techniques were established for generating realistic simulations of the appropriate mission material; the accuracies of the simulation processes were defined for most of the simulation technique; and the psychophysical study was effective in defining the increment spacings for a modulation transfer function (MTF) - ground exposure GEMS matrix array and the accuracy of the subjective judgments of each parameter.

Since a comprehensive final report was submitted at the completion of each program task, the program final report will serve to summarize the findings of the tasks and to discuss the potential implementation of GEMS in the evaluation of mission material.

1.2 PROGRAM OBJECTIVES

The GEMS Study program was concerned with seven basic tasks. The major objectives of each task are defined in the following subparagraphs:

1.2.1 Refinement of Techniques

In refining the simulation techniques of the GEMS modified contact printer, the primary objectives were to improve the precision with which each of the image quality parameters could be controlled and to determine the accuracy of the simulation processes. The simulation processes and instrumentation were up-dated in accordance with the study findings. This task was

later modified to include the study of MTF simulation control in the Pseudo GEMS Viewer concept.

1.2.2 Alternate GEMS Technique

In simulating MTF with the modified printer GEMS instrument, it was conceived that the control of this simulation parameter would be Fresnel diffraction limited at approximately 100 cycles per millimeter. In the anticipation of future simulation requirements above this upper spatial frequency limit, an alternate means of controlling MTF was investigated. The alternate technique investigated involved the use of a modified copy camera system where the spread function of the imagery was modified by controlling the size and shape of the copy lens pupil function.

1.2.3 System Parameters Study

Under the redirection of efforts phase of the program, the System Parameters study was initiated in order to obtain objective measures of such appropriate mission material parameters as MTF, ground exposure, and scene contrast; and such film-processing characteristics as the film sensitometric curve, film granularity, and film density neutrality. These objective measures were used in establishing the parameters of the psychophysical GEMS matrix.

1.2.4 Equal Magnification GEMS Study

Under the redirection of efforts phase of the program, the Equal Magnification GEMS study was established for the purpose of defining a technique that would permit realistic simulations to be generated at the same scale factor as mission material. This task evolved because ordinary negative material could not be employed in generating a GEMS master transparency with a

faithful reproduction of the ground exposure tonal scale. In addition, the control of the MTF simulation was influenced by the non-linearities in the toe and shoulder areas of the original film characteristic curve.

1.2.5 Psychophysical GEMS Study

The major objective of the Psychophysical GEMS study was to determine the usefulness of GEMS in the subjective evaluation of mission material. The objective was to be accomplished by psychophysical experimentation. The information to be acquired from this experimentation was to include:

a) the visual perceptible increment spacing of MTF and exposure,

b) the accuracy of the subjects' judgments of each parameter,

c) the uniqueness of each MTF-exposure element in a matrix array, and

d) a measure of the subject's ability to rank mission material with GEMS.

1.2.6 GEMS Viewer - Design Concept

If GEMS are to be employed in the evaluation of mission material, it is essential that a viewer be designed for handling both the GEMS and the mission material. The design features of such a viewer were established under this task. Consideration was given to such features as an automatic matrix element search mechanism, split field viewing, GEMS rotation, and variable magnification viewing.

1.2.7 Pseudo GEMS Viewer

It was envisioned that a GEMS viewer could be constructed where the parameters of MTF, ground exposure, and scene contrast would be

simulated by optical and electrical mechanisms within a viewer. The fabrication of a viewer of this nature would eliminate the need of a large film matrix array. This task was directed toward demonstration of the feasibility of this concept with a breadboard experiment.

SECTION II

SUMMARY OF TASK RESULTS

2.1 REFINEMENT OF TECHNIQUES

The Refinement of Techniques was concerned with investigating the following simulation processes and improving the simulation instrumentation.

a) MTF simulation on the GEMS modified contact printer

b) MTF simulation in the Pseudo GEMS Viewer

c) Exposure simulation

d) Haze simulation

2.1.1 Simulation Technique Conclusions

An analytical investigation was performed to determine the effects of near-field diffraction on the control of MTF when the MTF was simulated with the GEMS modified contact printer. The results of the investigation proved that the simulation of MTF could be suitably controlled below 100 cycles per millimeter. Above 100 cycles per millimeter the Fresnel diffraction effect introduces a sizable alteration in the shape of an edge gradient. The edge shape alterations are too extensive to allow the simulation of specific transfer function shapes in the high spatial frequency regions.

In the simulation of MTF with the Pseudo GEMS Viewer, non-linear film imagery must be convolved with the degrading linear spread function elements of the viewer optics. An analytical investigation was performed to determine the error that would result in the simulation of MTF when employing a negative scene as a master transparency. The investigation demonstrated that a 160 cycle per millimeter MTF simulation could be achieved with less than a 4 percent error for the full tonal range of the imagery. Errors of less than

2 percent would be introduced in an 80 cycle per millimeter MTF simulation. Percentage errors of this magnitude are quite tolerable.

Modification of the GEMS instrument with a well regulated light source has yielded exposure simulations within the tolerance limits of the evaluation equipment. A 0.02 density exposure shift can be simulated.

An analytical and experimental investigation was initiated to determine the accuracy of the haze simulation process. Due to the film effects, created by the double exposure process, haze simulations cannot be achieved with less than a 5 percent error by the present technique. By modifying the GEMS instrumentation with a non-image forming, d.c., light source, both the fogging exposure and the image exposure can be accomplished simultaneously; and the film effects would be eliminated. Simulating haze in this fashion is identical to a real haze situation except for shadow area back-scatter. The error of the simulation process then would be reduced to the error of the evaluation equipment. It is important to note that to obtain an estimate of haze with GEMS is not dependent upon the phenomena of shadow area back-scatter.

2.1.2 Instrumentation Conclusions

The GEMS instrument was modified with a film vacuum platen and a strobe flash unit. The vacuum platen and its associate jigging permit control of the master transparency-GEMS film separation to ± 0.0002 inches. At a MTF simulation level of 50 cycles per millimeter, the instrumentation variables for the modified contact printer can be controlled to ± 2 percent of the desired transfer function. At 100 cycles per millimeter the error increases to slightly less than ± 4 percent.

A strobe flash unit was installed to improve exposure repeatability and to eliminate the film Reciprocity Law Failure problems introduced by long exposure times. With the new source, an exposure repeatability of ± 0.01 density units is achievable. A ± 0.01 density variability is equivalent to the error of the densitometer used in the exposure evaluation process. It is quite possible that the source has less variability than can be detected with the evaluation equipment.

An aerial image read-out device was breadboarded in order to obtain more accurate measures of sensitometric data in a copy camera reduction system. In a copy system an error is introduced in the edge-gradient analysis sensitometric data if the lens fall-off properties are not taken into account. To obtain valid sensitometric data, sensitometric step readings must be obtained in the lens image plane. The breadboard device provided sensitometric data within ± 0.01 density units for the low density region and within ± 0.02 density units for the high density region.

2.2 ALTERNATE GEMS TECHNIQUE

The present use of a modified contact printer for the simulation of MTF provides predictable and controllable results over the spatial frequency range of 0 to 100 cycles per millimeter. It is desired to extend the MTF simulation capabilities to a higher frequency range; therefore, an analytical investigation was conducted to determine the validity of several alternate simulation approaches.

The alternate procedure established to be most valid involved the use of a modified copy camera system with a variable-transmission, spread function mask employed in the pupil plane of the lens for control of the image spread

function size and shape. A breadboard unit was constructed and some experiments were performed to demonstrate the feasibility of the simulation concept.

The investigation was considered to be highly successful in view of the fact that the only limitation was in the optics and not in the theories or techniques utilized. The optics problem can be easily remedied. Despite the limitation of the optics, the task produced several highly significant results.

First, the validity of the technique of MTF modulation by aperture apodization of a copy camera was conclusively demonstrated. That the technique was not demonstrated for spatial frequencies out to 200 cycles per millimeter as intended was, as stated, the fault of the optics used, not of the technique itself. The design of better optics will allow extension of this technique without serious difficulty to frequencies of 200 cycles per millimeter and beyond.

Second, the good MTF agreement obtained between the "theory" and experiment is an excellent demonstration of the repeatability and accuracy of the edge-gradient analysis technique itself; although this was supposedly not at stake here, it is a worthwhile corroboration of the method.

Third, the experience gained by encountering and partially surmounting the breadboard difficulties is valuable for future efforts.

2.3 SYSTEM PARAMETERS STUDY

The GEMS Study program is primarily concerned with the simulation of a particular class of aerial photography. The realism achieved in the simulation of this photography is dependent upon both the simulation techniques and a knowledge of the system parameters. Various talks with the customer's people

indicated that no objective measurements existed which would describe the mission material parameters in a manner directly related to the objective evaluation of the GEMS.

Under the redirection of program efforts, a task was established for the purpose of objectively defining both the film characteristics and the system performance factors. The goal of the study was to define the following parameters in suitable terms, for purposes of scaling and evaluating the GEMS matrices:

a) film sensitometric curve

b) film granularity

c) film density neutrality

d) system modulation transfer function (MTF)

e) aerial image contrast

f) scene exposure

The parameters of the study were defined in terms of objective measures which were apropos to the evaluation of GEMS and the use of [redacted] 25X1A

25X1A [redacted] facility photographic evaluation instrumentation.

The study data cannot be condensed to single numbers without losing significant information. For this reason, the data compiled in the text of the task report should be consulted for specific details.

To abstract summary measures pertaining to system performance factors, it can be stated that the study indicates the average aerial image contrast to be 0.274 modulation and the average scene exposure range to be a 0.44 density difference for the six scenes evaluated. Figure 1 presents a composite graph of the measured system transfer functions.

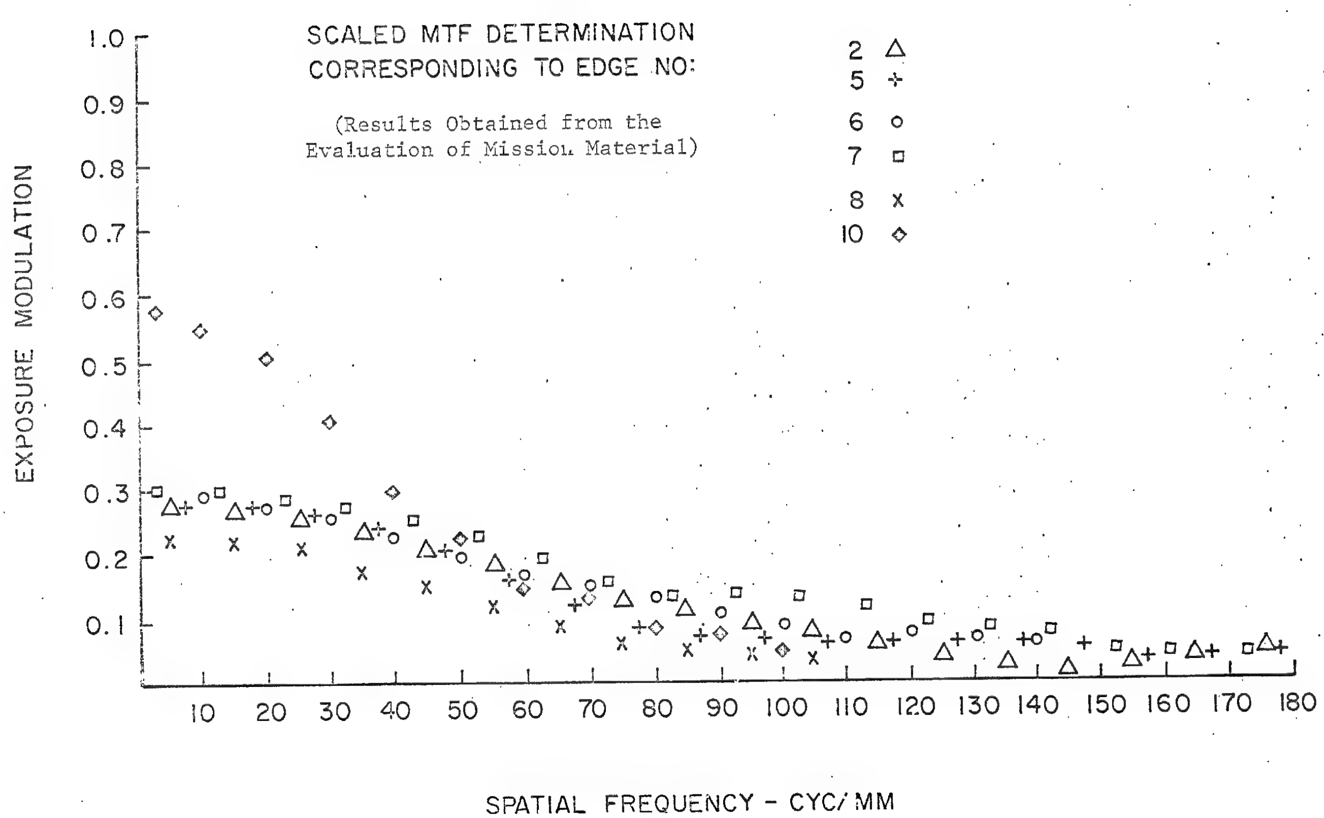

Figure 1 - Scaled MTF Determination Composite

The film properties provide a knowledge of the film response and imagery appearance. This data, as compiled, is to be used to ensure proper simulation of processing as well as to furnish a means of monitoring all variables which affect film granularity and density neutrality.

The System Parameters Study can be termed quite successful in that the data obtained served to define the operational level of a system whose performance is rated as "good" to "best." The data made available by this study was inclusive enough to give guidance in specifying and evaluating the various system parameters as related to the production of a psychophysical GEMS matrix.

2.4 EQUAL MAGNIFICATION GEMS STUDY

Earlier GEMS efforts established the fact that the appropriate program mission material could not be simulated from an original negative that was processed to a high gamma and/or photographed under conditions that introduced either a substantial degree of atmospheric haze or a compressed scene exposure range. The Equal Magnification GEMS study was initiated to investigate not only the properties that a transparency must possess to yield a valid simulation, but also the proper technique of performing the simulation. The study treated all phases of the simulation topic. It clearly defined the system parameters to be simulated and used these parameters as guides in developing the overall aspects of a total procedure which would yield realistic simulated photographs.

The study results concluded that to properly simulate MTF, exposure, and contrast, requires both a unity gamma, positive transparency with a large, linear film density-exposure range; and a modified copy camera for simulating MTFs above 100 cycles per millimeter. A positive transparency of the nature

described above is necessary in the simulation process, because the accuracies of the simulations are dependent upon the modification of imagery which is linearly related to the exposure domain. A modified copy camera is essential in order to predictably control MTF and to avoid the effects of Fresnel diffraction.

An experimental film study established that imagery obtained with DuPont SR-102 negative reversal film would satisfy all the positive transparency requirements.

2.5 PSYCHOPHYSICAL GEMS STUDY

A psychophysical study was conducted to determine the usefulness of GEMS as a subjective evaluation tool. The study results definitely established the fact that GEMS can be employed to obtain realistic estimates of system performance. The study experiments provided valuable information pertaining to the matrix increment spacings for MTF and ground exposure, the uniqueness of each parameter, the precision of the judgments, and the ability of interpreters to rank mission material with GEMS.

2.5.1 Parameter Scaling Findings

The study results established that equal, visually discriminable steps of MTF and exposure are obtained for the ranges of the parameters tested if the increments of MTF are spaced at equal logarithmic steps and the increments of exposure shift are spaced at equal density steps. A 67% accuracy of discrimination is obtainable when the MTF steps are established at 12.5% ground resolution increment intervals and the exposure steps are established at 0.06 density shift intervals.

The results imply that an exposure shift interval of 0.06 density units is too fine for camera system evaluation purposes since no changes

in resolution due to exposure were discernable for the entire simulated exposure range of the GEMS. For the GEMS matrix, it is suggested that the exposure increments be established to correspond to exposure shifts that produce 12.5% changes in limiting ground resolution.

An MTF interval of 12.5% ground resolution steps is as fine an increment spacing that can be discriminated with reasonable accuracy. It is suggested that this interval be established as the increment spacing of the GEMS matrix array. With the use of a split field viewer for making comparisons, the accuracy of MTF discrimination may be improved.

2.5.2 Other Study Findings

The experiment concerning the ranking of mission material with a GEMS matrix indicated that the subjects' judgments of the MTF and exposure levels of the mission photographs were just as reliable as their judgments when ranking one GEMS against another. In other words, the standard deviations of their judgments for each parameter were statistically the same in both experiments. The accuracy of the judgments could not be determined since no objective measures were made of the mission photographs used for the study.

A very important finding of the study was that scene content seemed to have no effect on the subjects' ability to judge MTF or exposure. This finding strongly suggests that the parameter of scene content can be confined to few scenes of various type imagery.

2.6 GEMS VIEWER STUDY

A concept design study was performed to define the features most desirable for a GEMS Viewer. The established instrument design concept will

enable rapid image quality assessment of roll film aerial photography with GEMS. The instrument was designed to provide rapid assessment capabilities by consideration of the following features:

1. Means for easy storage and quick retrieval of a library of known-quality images. The retrieval system will enable an operator to select a GEMS having known quality values.

2. Means for rapid screening of original negative roll film. The instrument will include a motorized roll film transport, designed to insure safety of roll film, and a variable intensity light table.

3. Means for viewing the roll film images and the reference images (GEMS), simultaneously.

4. Means for manipulation of the two images to permit convenient positioning for optimum viewing.

A dual split-field presentation was chosen as the optimum device for viewing two photographs simultaneously. The operator will see a split field, each half containing an image to be compared.

This viewer must not degrade the images and yet must contain a variety of adjustments to allow the operator to magnify and orient the images to suit his individual preference. It was necessary to design an optical system specially for the GEMS Viewer in order to accommodate the unique optical paths, maintain the resolution of the images, and provide the magnifications and image motions required to permit rapid comparison of photography.

It is also important that the comparisons between the unknown images recorded on roll film and the known images recorded on GEMS be done in rapid

succession, with a minimum of operator distraction. This requires a fast storage and retrieval system with a simplified call up. A commercial address type system was chosen for this application. Mounting four GEMS per address (slide) increases the library storage capacity to 1024 GEMS.

Images recorded on the roll film must be located and positioned in the field of the microscope and oriented to the GEMS images. Because this may be irreplaceable material, attention has been given to the film transport system to ensure the safety of the film. Constant tension is required in order to maintain focus and prevent inching. A variable speed film transport is required to minimize search and positioning time.

The instrument is to be mounted on a hard wood table with the microscope optical axis at a 15 degree downward tilt. Pertinent aspects of human engineering have been carefully considered to minimize operator fatigue and maximize convenience and speed of operation.

The operation of this instrument will be simple even though it contains a variety of features. Many of these features, although important, are adjustments used only on a "once per roll" basis (or even less frequently). In addition, some operations are combined (e.g. joy sticks to control both X and Y movements, simultaneously). Further, all the controls have been carefully located to facilitate manipulation at minimum operator effort. No problems are anticipated in the operation of this equipment over long periods of time.

While this instrument has been designed to permit mission diagnosis by comparison of photography and GEMS, it is clear that the instrument can be easily applied to several other aspects of the overall photo-interpretation

process. For instance, with little or no modification, the instrument can be used for training of new personnel, for assistance in target identification, and for change detection. Other potential applications may become apparent later.

2.7 PSEUDO GEMS VIEWER STUDY

A Pseudo GEMS Viewer optical breadboard was constructed. The breadboard was used to test the concept of manipulating the photograph scene parameters of MTF, exposure, and contrast with optical and electrical mechanisms. Such a device, if it produced realistic simulations, would eliminate the need of a large matrix library of GEMS.

The study showed that reasonable matches could be obtained for the scenes employed, but theoretical considerations imply that the technique is inadequate for the simulation of the appropriate mission material without further refinement. It was established under the Refinement of Techniques task that the physics of a hazed aerial scene is actually the reduction of the ground imagery signal level by a superimposed, non-image forming, d.c. light level in the exposure domain.

To achieve an accurate haze simulation in the Pseudo GEMS Viewer with only the use of non-image forming light and a transparency, the density distribution of the viewer transparency must be made linearly proportional to the original ground exposure distribution. In the above arrangement, a linear relationship between film density and ground exposure only exists for a positive transparency whose cascaded gamma is unity. Since the pseudo concept must employ a negative transparency with a gamma of approximately 2.2, the resulting haze simulations will not be valid.

The pseudo breadboard experiment did not identify this flaw in the concept, because positive transparencies with a cascaded gamma of unity were employed. However, by inspecting the degraded photograph supplied in the Pseudo GEMS experiment report, it can be seen that the low and high density images were not identically matched. This mismatch at the density extremes occurred because the toe and shoulder areas of the film characteristic curve departed from unity gamma. If gamma 2.2 negative transparencies had been employed in the breadboard experiment, considerably more of this type of dissimilarity would have resulted.

Exposure shifts also cannot be accurately simulated by the experimental pseudo approach, because of the negative transparency's non-linearities. The GEMS concept eliminates the non-linearity problem by employing a unity gamma, positive, master transparency in the simulation process.

SECTION III

PROGRAM CONCLUSIONS

3.1 TECHNOLOGICAL STATUS

The efforts of the GEMS Study program can be termed quite successful. All of the major objectives of the program have been achieved. Studies pertaining to the development of simulation techniques have led to the establishment of means for accurately controlling the production of realistic photographic simulations.

The problems associated with generating GEMS at the same scale factor as mission material were defined, and a procedure has been specified for eliminating all apparent simulation difficulties. The key factor that allows the generation of realistic simulations is the possession of a positive master transparency whose image density distribution is linearly proportional to the ground exposure distribution.

In the simulation process, such a transparency permits the modification of image spread functions and the introduction of ground exposure shifts and varying degrees of atmospheric haze in identically the same manner as what normally occurs in real life, except for the effect of atmospheric haze back-scatter into shadow areas. Fortunately, subjective estimates of contrast are not dependent upon the phenomena of back-scatter.

The realism of the GEMS simulations was substantiated in the psychophysical study where it was demonstrated that photo-interpreters could subjectively estimate the image quality of mission material with the same degree of reliability as the ranking of one GEMS against another. The psychophysical

study also established the matrix increment spacings for the parameters of MTF and exposure as well as the accuracy of the judgments of each of these parameters.

3.2 USEFULNESS OF GEMS

It is essential to establish that the general concept of GEMS is useful. The usefulness of GEMS can be determined by examining the accuracy with which the parameters can be judged. The psychophysical study results demonstrate that a photo-interpreter can judge both a MTF increment spacing of 12.5% ground resolution steps and an exposure increment spacing of 0.06 density unit steps with a 67% confidence of proper discrimination. Their ability to discriminate levels of exposure is better than is necessary. Although their discrimination of MTF levels may be slightly less sensitive than desired, reasonable estimates of MTF levels are obtained.

Serious consideration should be given to the point that the GEMS estimates of MTF are almost as accurate as the MTF objective determinations of mission material, because of the variable factors associated with the typical targets used in the measurement process. Under certain conditions, where the quality of imagery is varying over the format and no objective measurement targets exist in the areas of interest, the MTF estimates obtained with GEMS can be much more accurate than any inferred evaluations. Image quality variations occur quite frequently due to variable haze conditions or variable cloud coverage exposure conditions.

The attributes of GEMS are another factor to be considered in determining the usefulness of GEMS. The major attributes of GEMS are that they can supply estimates of system performance quite rapidly and that these estimates are not dependent upon either specific type targets or complicated instrumen-

tation that requires lengthy operator training time. It probably would require a minimum of 4 to 8 hours to objectively evaluate, without an on-line computer to the instrumentation, the parameters of a single scene area that could be estimated with a GEMS matrix in a matter of a few minutes.

In summary, the psychophysical study demonstrated that GEMS can provide a useful service as a rapid evaluation tool.

3.3 PROGRAM RECOMMENDATIONS

At the last program review conference with the customer, [redacted] 25X1A stated that it would objectively evaluate both the GEMS and Pseudo GEMS concepts; and to recommend on the basis of the technical soundness of each approach, the concept that would best serve the customer in his systems' evaluation work. The findings of the various study tasks definitely establish, without any doubt, that the GEMS concept is the most valid approach for acquiring accurate diagnostic estimates of system performance at this time.

When considering the facts, the simulation technology has been developed, the psychophysical parameter scaling has been determined, and the appropriate system parameters have been defined, implementing a GEMS matrix as an evaluation tool can be accomplished in a fairly routine fashion. It amounts to generating the GEMS library material and fabricating a GEMS Viewer which has already been designed. It is our recommendation that the GEMS concept be implemented.

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Approved For Release 2002/06/17 : CIA-RDP78B04747A000700010025-7